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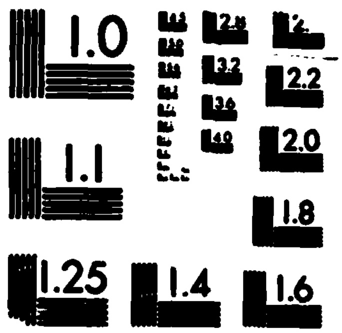

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FIELD PROCEDURE FOR MEASUREMENT OF FLIGHTLINE OFFSET IN FORESTRY SPRAYING

PROCÉDÉ SUR LE TERRAIN POUR MESURER LA DISTANCE DE DÉCENTREMENT DE LA LIGNE DE VOL DANS UNE OPÉRATION D'ÉPANDAGE DES FORÊTS

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PREFACE

The National Research Council Associate Committee on Aerial Forestry Applications (ACAFA) has, for some time, recognized the need for good field experiments in far-field drift and forestry spray research; however, there exists a certain lack of definition of what constitutes a good or meaningful field trial. In response to this need, the director of the National Aeronautical Establishment requested that the authors prepare a short report on the design of a 'definitive' field experiment focusing on the flightline offset problem. A preliminary Laboratory Memorandum was subsequently produced and distributed to some members of ACAFA for review.

This final report presents the design of a suitable field experiment in aerial forestry spray research and reflects the comments of ACAFA members.

ABSTRACT

Some general remarks are presented on the design of a definitive field experiment on windborne droplet drift and deposition in aerial forestry spray applications. The role of the uncontrollable parameters, i.e. forest properties and, in particular, meteorology, is emphasized. Then, the variables in one aspect of the problem, the flightline offset distance, are discussed and an example of a suitable, i.e. economical but adequate, field experiment is described.

RÉSUMÉ

Certaines remarques concernant la mise au point d'une expérience sur le terrain sur la portée éolienne de gouttelettes et dépôt d'une opération d'épandage des forêts sont présentées. L'accent est mis sur le rôle des paramètres incontrôlables, e.g. les caractéristiques de la forêt et la météorologie. Aussi, les variables concernant un aspect particulier du problème, la distance de décentrement de la ligne de vol, sont discutés et un exemple d'une expérience sur le terrain relative à cet aspect est décrit.

CONTENTS

I. Introduction

Among results from different field experiments on target deposition and off-target windborne droplet drift in aerial forest sprays, there can be disagreement due chiefly to:

a) differences in target stand characteristics which influence their droplet interception efficiencies, including mean wind speed profiles above the forest, nature and density of the stand and average size and orientation of foliage elements;

b) differences in the mean and turbulent structure of the temperature, humidity and vector wind fields both in the canopy flow and in the atmospheric surface layer flow above the stand, all of which influence the sink velocity and decay rate of the aircraft vortex wake containing the ultra-low-volume(ULV) spray emission (thereby determining the effective spray release height) as well as the turbulent deposition velocity of the droplets;

c) differences in aircraft spraying altitude and in wingspan and span loading which influence both the initially large downwash velocities in the wake prior to vortex sheet roll-up and the subsequent wake sink velocity, thereby affecting the location of the upwind edge of the deposition profile; and

d) differences in the atomizer characteristics as they influence the initial droplet size spectrum and in the physical and chemical composition of the formulation as they influence the evaporation rate, final droplet size and terminal velocity and spray impaction characteristics, eg. dry particulates from evaporated aqueous fungicide sprays impact differently from droplets.

In any field experiment, a number of the above variables are controllable, eg. aircraft type, flying height and span loading, and atomizers and formulations. The others, forest stand parameters and the meteorology cannot be controlled. Thus, in any series of field studies in which the effect of the uncontrollables is assessed by systematically altering them among tests, at least two forest stands of differing characteristics should be used to demonstrate the effect of target properties on droplet deposition and off-target drift, and the effects of a number of different meteorological conditions should be investigated; included among the latter are the strength of the pre-dawn surface-based inversion (the traditional spraying period), the degree of instability and hence

turbulence intensities in shallow and deep convective mixing and the effect of wind speed in neutral flows.

The above requirements suggest a certain degree of economy is possible in acquiring the necessary data on the effect of the uncontrollables. Thus, the effect of meteorology on deposition and drift for a given forest, spray aircraft configuration, formulation, etc., could be assessed in as few as seven tests comprising

(i) two for the effect of wind speed in neutral flow,

(ii) three for the effect of thermal stability from strong inversion to strong convection

(iii) two for the effect of convective mixing layer depth, i.e., inversion base height.

The effect of altering the stand properties, essentially the areal density profile, could then be estimated in one further test by comparing these latter data to the appropriate data set from the first seven tests. However, it is unlikely that all forest areal density profiles could be assigned to one or other of two categories so that three or more examples may have to be examined. This result could raise the minimum number of tests on the uncontrollables to unwieldy values; consequently, the influence of stand density may well be deferred to a subsequent set of trials.

II. The offset distance in aerial forest sprays

Of the controllable parameters, aerodynamic downwash has the major influence on deposition as already demonstrated by the USDA using a rotary wing and a fixed wing aircraft in an orchard spraying test. (Is it necessary to repeat this test?) Aircraft height is not normally a parameter, given the operational practice of flying as close to the trees as is safe; in the case of Grumman TBM operational spraying, this is generally about 30 m above the trees. For lower spraying altitudes of 10-15 m above canopy, the near-field deposition profile is largely determined by the downwash as evidenced by the vortex-wake sink velocity, and the mean wind speed between release and the forest canopy.

Careful field measurements of foliar deposition from experimental ULV (Ultra Low Volume) aerial spray applications in the New Brunswick forests (Van Vliet, 1986) are used to identify the location of the leading edge of the deposition profile, or flightline offset. The resulting

values together with two theoretical estimates, one from the traditional Porton model and one from a recently developed NRC model are tabulated below. The models are described in Appendix 1. The variables in the NRC model are spray release height , droplet terminal velocity, windspeed and turbulent transport; the Porton model neglects turbulent transport. Only results from cases having wind direction within 30° of the perpendicular to the sprayline are included. In the table below, U is the windspeed at aircraft height.

A/C	Ht(m)	U(m/s)	Stability	Meas offset(m)	Model Results NRC	Porton
TBM	44	5.9	Neutral	40	41	115
C188	59	7.0	Neutral	100	85	212
TBM	38	4.2	Neutral	21	21	81
C188	39	4.2	Neutral	21	24	84
TBM	31	3.1	Stable	<25	17	40
C188	40	4.0	Stable	<25	40	73

This data set is too sparse to be useful in all situations; in particular, it applies to a rather open forest and a limited range of aircraft heights and thermal stabilities. The model/data comparison, on the other hand, appears satisfactory for the NRC model, particularly for the near neutral cases. The hazard of neglecting turbulence is illustrated by the poor performance of the Porton model which appears to have little utility in this problem.The NRC model/data agreement indicates, however, that detailed turbulence measurements are required to predict the position of the leading edge of the deposition profile. It is unlikely, however, that the aerial applicator would have access to the necessary turbulence data at spray time.

Clearly, then, more complete field data are required to parameterize offset distances in aerial forest spray applications in terms of aircraft speed, height and configuration and in terms of atmospheric windspeeds, turbulence and thermal stability.

Additional modeling studies are recommended as well. These models should include not only the vortex sheet roll-up process but also the interactions of the trailing vortices with the above- and in-canopy flow in a forest. Theoretical predictions of this situation in <u>open terrain</u> appear in Bilanin et al (1987) and Weihs et al (1987), while Picot (1987) has developed a promising model for the forest case which requires further field validation. These models have potential for predicting the location of the <u>peak</u> of the deposition profile inasmuch as this depends on the properties of the vortex wake flow field and its interaction with the ambient flow field. The above analysis, on the other hand, indicates that background atmospheric turbulence is the important mechanism in determining the

location of the leading edge. Until turbulence measurements are routinely included in operational spray applications, however, offset distances in forest sprays are best parameterized by more extensive field measurements.

III. Example of a field experiment to determine offset

The experiment should be conducted in flat, uniformly forested terrain using a grid similar to that appearing in Fig. 1. The baseline data returned from this study would not only apply to the operational situation in flat topography but would also be applicable to nominally undulating topography inasmuch as the atmospheric surface layer flow is terrain-following in these circumstances. This flow is routinely predictable by the mass-consistent windfield technique (Sherman,1978), but the accuracy of the prediction depends on the number of discrete windspeed measurements in the area concerned.

The aircraft spraying height should range from 10 to 30 m above canopy to cover the entire anticipated operational range. A single line should be treated with five swaths overlaid at three-minute intervals in order to average the effects on offset distance of random aircraft motions and of fluctuations in instantaneous wind speed profiles. As described in III(a) below, this experimental protocol yields a reasonable approximation to the expectation value of offset and therefore the most likely occurring value for the case of a single swath. The approximation improves with the number of overlaid swaths, but more than five may tax the available resources. The line should be flown over uniform forest inasmuch as the preponderance of small aircraft targeted sprays today are to discrete woodlots immersed in otherwise continuous forest. The alternative situation of a physically isolated woodlot would have a very different spray offset distance for a given aircraft height, windspeed, etc., and would be less representative of the current Canadian scene. Figure 2 shows (a) the Grumman TBM and (b) the Cessna 188 spraying a line over horizontally homogeneous forest in a controlled field experiment in New Brunswick in 1986.

The controllable parameters in this field study are aircraft type and speed, formulation and atomizer. Suitable combination of these parameters determines the aerodynamic downwash velocity and the initial droplet-size distribution as well as its evaporative behaviour. For the purposes of this investigation, the choice would be fixed-wing sprayer flying at three different speeds in order to cover a range of aerodynamic downwash. A non-volatile formulation, eg., 2% TEHP in dibutyl phthalate should be used to represent the increasingly-used undiluted pesticide formulation in ULV

applications. Dibutyl phthalate has similar physical properties (viscosity,surface tension and density) to a widely used insecticide, fenitrothion. This formulation, either 'neat' as indicated above, or in aqueous emulsion is preferred over toxic chemicals to avoid effects on wildlife from overtreatment of the test site. Micronaire is the atomizer of choice in order to minimize the production of 'large' droplets and to ensure both that the resulting size spectrum is representative of ULV emissions and that vortex wake wind shear dynamics control the near-field droplet trajectories.

Other atomizers such as the Teejet (flat fan) could be employed in an extension of this study. Further extensions could employ a rotary wing sprayer and different canopy characteristics.

The uncontrollable parameters of the aerial spray offset problem are the meteorological situation and the forest characteristics. The influence of the latter should be dealt with in a further study as suggested above. Since the swath displacement is influenced by crosswind as well as by downwash, and both are functions of atmospheric thermal stability, the flying schedule should yield data to identify the effects of all important combinations of these variables. Thus, for a flying height at the low end of the operational range where thermal stability is of minor importance, the major parameters are downwash, i.e. aircraft speed for a specific mass and wingspan, and windspeed, while at the high end of the operational spray altitude range, the downwash diminishes in importance relative to thermal stability and windspeed. These considerations indicate that a minimum of 10 trials are required as follows:

Aircraft Height	Aircraft speed			Thermal Stability				
(m agl)	low	normal	high	very stable	neutral low w.s.	neutral high w.s.	very unstable	number of trials
25	x	x	x		x	x		6
45		x		x	x	x	x	4

For the 25 m height, the aircraft would be flown at the three speeds indicated for each of the high and low windspeed neutral stability conditions, resulting in six trials.At the 45 m height, aircraft speed is kept constant and four trials are required to cover the entire range of atmospheric stability including the effect of windspeed.

The ten trials include the five previously shown as sufficient to assess the effects of windspeed and atmospheric stability as well as an additional five to determine the effect of aircraft height and configuration. Since the scale of the experiment is short range, the effects of mixing layer depth are omitted. The above schedule exploits the enhanced information return on the effect of aerodynamic downwash by using large variations in aircraft flying speed. It represents the minimum experimental effort required; prudence suggests each case included in the table should be documented with at least 2 replicates.

The above data set should be sufficient to enable the ULV forest spray applicator to select the flightline offset for a given aircraft weight, height and speed if the forest characteristics as well as the windspeed and temperature profiles to aircraft height are known. The applicator presumably is able to estimate stand properties, and while on-site data on the windspeed and temperature profile to aircraft height would be needed in an operational woodlot aerial spray, these may be estimated using minimal instrumentation as described in (b) below.

III.(a) Field measurements during the experiment

The basic field procedure would be to fly the schedule described earlier, having selected the forest and established the flight lines. Figure 1 is a sketch of a suggested sampling grid for measurement of flightline offset. Two one-km long lines intersecting at 120° with sampling on the bisector could ensure that all mean wind directions clockwise from, say, 210° M to 330° M, the usual wind directions in summer in southern Canadian inland regions, are no more than 30° away from the perpendicular to the sampling line. For each flight, the leading edge of the foliar deposition profile would then be measured to form the data bank on flightline offset. Aviation weather forecasts are helpful when selecting test days (essentially days of precipitation-free VFR weather) although they rarely account for the difference between surface and gradient wind directions over rough terrain so that the choice of flightline must be made on-site at spray time.

The preferred technique for measuring the swath displacement, or flight-line offset, is to deploy an array of Rotorods (RR) along the bisector at mean tree height. RR's, as active samplers, will reveal the presence of windborne droplets which are too small to impact passive samplers such as foliage simulators. The longitudinal RR spacing orthogonal to the flightline should be of the order

of 6 m and the rotorod should extend from one semi-wake width upwind to 100 to 200 m downwind depending upon aircraft spraying height. Overloading of the Rotorods in the swath is not considered a problem inasmuch as the goal of this investigation is the identification of the offset, not the quantitative measure of atmospheric droplet concentration.

To determine the expected level of far-field wind drift, a 10-Rotorod array to 300 m above ground level (agl) could be suspended from a captive blimp at 1 km downwind. These data would also reveal whether increasing the spray height also increases the far-field wind drift in proportion. For the problem at hand, these measurements are optional; omitting them permits a reduction in flight line length from 1 km to ~500 m.

Other experimental methods of measuring swath displacement are available. The most direct is analysis of samples of the upper foliage for the presence of the spray material. However, this technique is not only labour intensive and destructive but is unusable after the first flight due to contamination of the remaining foliage.

An alternative procedure consists of using LIDAR to map the trajectory of the spray cloud. However, while the use of LIDAR for tracking aerial spray emissions has been demonstrated on elaborately instrumented test ranges, its cost and onerous siting requirements probably remove it from consideration for the problem at hand. More recently, AES has developed a mobile spray cloud mapper (see Mickle, 1987) which could be more feasible for use in the forest scenario. DREV is also reported to have a mobile particle cloud mapper.

For the present, however, the experimental procedure recommended here is based on the use of RR's to determine the offset distance. At the same time the swath width could be identified from the RR deposit profile, extended, if necessary, by omni-directional passive droplet samplers (currently under development at the NRC) at tree height. The passive samplers are considered to be less susceptible to overloading and should therefore provide an unbiased measure of swath width.

If the RR's are renewed for each of the five swaths constituting a trial, then not only the mean value of offset distance, but the probability of other values for ostensibly the same spray scenario would be known, at least approximately, by applying statistical theory to the results. However, the logistics required for such an experimental protocol may exceed the resources available. In this case emphasis would be on extracting the mean offset distance from the measured longitudinal profile of RR

deposit integrated over five swaths, possibly a somewhat subjective procedure. The alternative of determining flightline offset from a single swath would be subject to the large uncertainties described earlier.

III. (b) Experimental procedure

The following assumes the availability of a spray aircraft fitted with atomizers, of mixing facilities, ground support, etc.

(1) Locate the forest and identify the ends of the (intersecting) flight lines with high visibility markers above the trees. Locate the centreline bisecting the included 120° angle.

(2) For a controlled experiment of this nature, the temperature and windspeed profiles to aircraft height are required. These data can be measured directly from a mast instrumented with simple thermistry and anemometry, eg. cup anemometry, at several levels up to aircraft height, i.e. 30-50 m agl, or from a 30 m mast instrumented at two levels, say 20 and 30 m agl, with instrumentation of turbulent flux quality , eg. fast response thermistors and propellor bivane or sonic anemometers, and applying surface layer theory to extend the profiles to A/C height. If the stand aerodynamic characteristics are already known, a shorter mast with fast response instrumentation at one level above the trees is enough. This procedure, described in Appendix 2, may be the one most frequently used in operational scenarios.

(3) Raise the sampling masts fitted with RRs at tree height. The RR orientation is not crucial. The sampler deposits should be obtained and analyzed as in Crabbe et al(1985).

(4) Prepare the spray formulation and load sufficient volume for at least fifteen minutes of spraying.

(5) Fly the aircraft for the flight line offset distance at the 25 m spray release height by flying it crosswind (select the appropriate flight line) at the three airspeeds, in a light-wind near neutral scenario. Repeat the flight later in higher-wind-speed neutral flow. Logging of meteorological variables should continue throughout both periods. Change the spray altitude to 45 m and fly it at normal airspeed in the three stability regimes selecting both low and high wind speed scenarios in the neutral case (this portion of the study may take some time). The first flight in this series should occur pre dawn to exploit the strong surface based inversion prevailing at that time. The

light wind speed neutral case may be the most difficult to document since it tends to occur infrequently; experience suggests the evening period for this case.

IV. Concluding Remarks

The variables affecting the deposition and off target windborne droplet drift in aerial forest spray applications are presented as possible reasons for the discrepancies among different field studies of this problem. It is shown how the uncontrollable parameters, namely forest stand properties and meteorology can have a major influence even when the controllable parameters such as aircraft type, height, speed, span loading, atomizer and formulation are identical from one test to another. It is argued that the role of the uncontrollable parameters can be assessed in as few as seven field trials for a given set of stand properties.

The flight line offset or swath displacement problem is discussed and a comparison is drawn between some observed values and a new theoretical prediction based on background atmospheric turbulence. It is concluded that the model/data comparison, although encouraging, is too limited to be of general operational use and an example of a field study to parameterize this problem in terms of aircraft height, downwash, windspeed and atmospheric thermal stability is described. Several experimental options are presented for determining the offset distance and one, based on the use of Rotorods at closely-spaced downwind intervals, is recommended.

V. Acknowledgement

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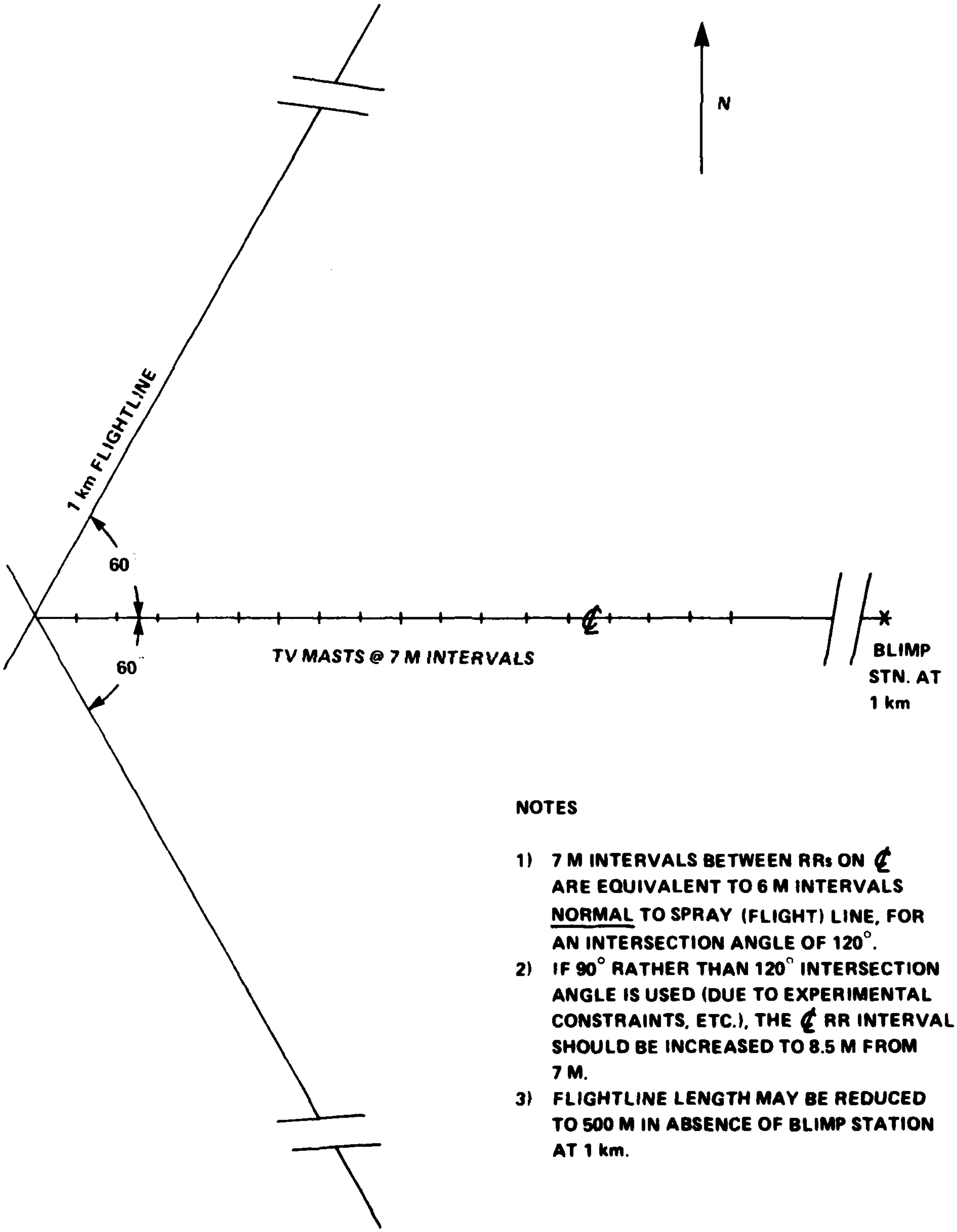
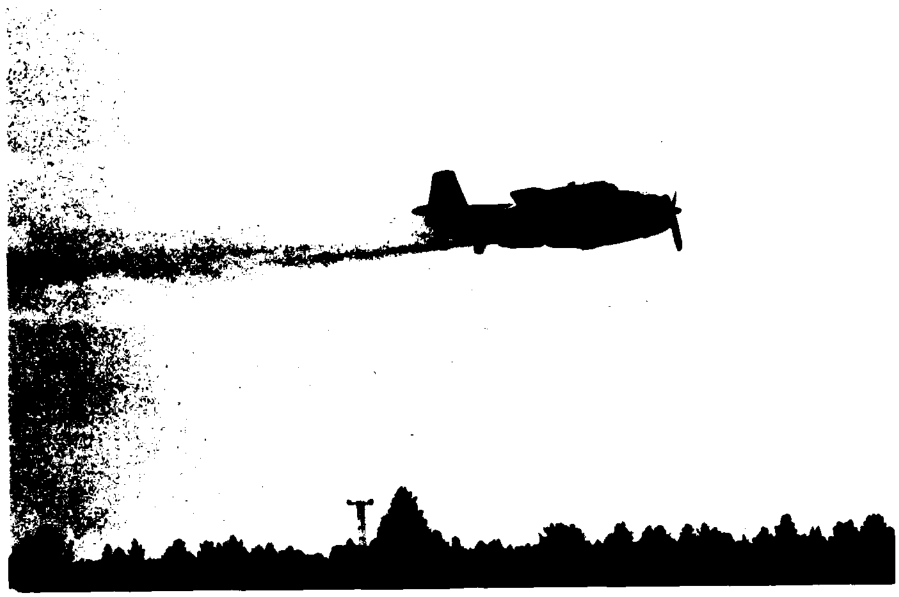


NOTES

1) 7 M INTERVALS BETWEEN RRs ON ℄ ARE EQUIVALENT TO 6 M INTERVALS <u>NORMAL</u> TO SPRAY (FLIGHT) LINE, FOR AN INTERSECTION ANGLE OF 120°.
2) IF 90° RATHER THAN 120° INTERSECTION ANGLE IS USED (DUE TO EXPERIMENTAL CONSTRAINTS, ETC.), THE ℄ RR INTERVAL SHOULD BE INCREASED TO 8.5 M FROM 7 M.
3) FLIGHTLINE LENGTH MAY BE REDUCED TO 500 M IN ABSENCE OF BLIMP STATION AT 1 km.

FIG. 1: SUGGESTED SAMPLING GRID FOR AERIAL FOREST SPRAY OFFSET



(a) GRUMMAN TBM

(b) CESSNA 188

FIG. 2: AERIAL FOREST SPRAYING

APPENDIX 1

The model presented here for the flight line offset distance contains the following assumptions:

1) Only the largest droplets in the ULV emission (250-300 microns) determine the leading edge of the longitudinal deposition profile.

2) Of these droplets, only those from the inboard atomizers (remote from the wing tip) are important in the present problem inasmuch as their initial motion is nearly vertically down with little spanwise motion toward the tip vortices.

3) The initial sink velocity of these droplets is the sum of their terminal velocity V_s (1m/s) and the aerodynamic downwash at the inboard portions of the wing trailing edge, $5W_v$ where W_v is the rolled-up wake descent velocity (Wickens,1979).

4) These droplets have sufficient inertia to move below the vortex sheet as the initial sheet sink velocity decays rapidly to the value W_v. Thus, the influence of the aircraft's trailing vortices on these droplets does not persist beyond vortex sheet roll-up time. At this point, atmospheric wind and turbulence in combination with the droplet terminal velocity govern their motion to the point of deposition on the foliage.

5) The structure and intensity of the turbulence is horizontally homogeneous so that turbulence data remote from the flightline applies in the neighbourhood of the emission. This assumption should be a satisfactory description of the situation at the Dunphy site in the New Brunswick forests (Crabbe et al ,1984,1985) inasmuch as windspeed profiles measured by NRC tower anemometry, AES tethersonde and UNB minisondes several kilometres away, were all in reasonable agreement and the forest is horizontally homogeneous.

6) Finally, these droplets, having relatively large sedimentary motion, are influenced by the negative vertical velocity components of the background turbulence rather than by the positive components. Using the equation of droplet motion and sigw as a scaling velocity for vertical turbulence, it is easily shown, at least approximately, that the droplet vertical velocity lags positive vertical air motion by V_s+2*sigw and negative vertical air motion by V_s-2*sigw. With V_s=1 m/s and sigw=0.5 m/s, a not atypical value, this simple argument illustrates the large differences in the response of the droplet vertical velocity

to positive and negative vertical air motion. As expected, the droplets track negative air velocities more faithfully than positive velocities. The result will be a reduction of the effect on droplet motion of positive changes in vertical air motion relative to negative changes.

The above assumptions are now implemented in the calculation of the flightline offset, or swath displacement, measured by UNB in the 1986 Dunphy field study (Van Vliet, 1986). Using tower data as well as aircraft height data supplied by UNB (Kristmanson,1986), that swath, of the 5 overlaid on the flight line in each trial, having the lowest release height, H, (and minimum windspeed) was selected as the one setting the leading edge of the measured deposition profile (offset distance). The 6-min record of tower turbulence data for this spray pass (each trial lasted 30 mins) was then analyzed to extract those periods (of length equal to the Lagrangian integral time scale, assumed to be $0.5*(z-d)/\sigma_w$ where z is height, d is the forest aerodynamic displacement length, 11m, and σ_w is the standard deviation of the vertical turbulent velocity components) with the largest average negative turbulent velocities. For example, the results from Dunphy/86 Trial #2 (neutral) turbulence data, when expressed in terms of the computed slope of the droplet trajectory (ratio of downward velocity to longitudinal velocity), are tabulated below:

Z(M)	DROPLET TRAJ SLOPE
63	-0.299
38	-0.417
25	-1.364
18	-0.727
10	-0.727

In this table, the 10m height is in the canopy where a constant slope is assumed. Broadly similar profiles were extracted from the turbulence records in several other near neutral trials.

To compute the offset, the slope profile is integrated from the effective release height to the height of the highest UNB foliage droplet sampler, 12m. Based on assumption 3 above, the effective spray release height for the Grumman TBM spray plane is approximately

$$H=HAC-(V_s+3W_v)T_r$$

where HAC=aircraft height above ground
W_v= vortex wake descent speed
$=8L/\rho\pi^3$ VSA, and
T_r=vortex wake roll-up time
$=0.14\rho b^3V/L$ (Wickens, 1979).

In this equation, ρ is the air density and b is the aircraft wingspan. For the TBM at V=77m/s,with lift L=8000kg and wing aspect ratio A=6, W_v=0.8 m/s and T_r=0.8 s using a value of b=16.5 m and ρ = 1.2 g/l. Thus, H is 3 m below HAC in the case of the TBM. The equivalent value for the C-188 is 2 m at a speed of 49 m/s with lift L=1800 kg and A=8. S is the wing area,= 45.5 m^2 for the TBM and 19.05 m^2 for the C-188.

Three cases for each aircraft were examined from the 1986 experiment. Flightline offsets predicted from the above model are compared in Sec. 3 to the observed leading edges of the longitudinal deposition profile.

Predictions using the traditional method of estimating offset distances, sometimes referred to as the Porton HU method, are also compared in Sec. 3 to observed values. This method neglects effects of turbulence and uses only aircraft height, windspeed between aircraft and forest, <U>, and the droplet terminal velocity. This resulting equation for offset distance for each droplet size is,

$$X_{off}(D) = (HAC-h)\langle U\rangle/V_s(D)$$

where h = mean tree height, D is the droplet diameter and <U> is the depth-averaged windspeed given in Appendix 2.

APPENDIX 2

By measuring the vertical turbulent fluxes of heat, $\overline{wT}$, and momentum, $u^{*2} = -\overline{uw}$, at a single height level above the trees, it is possible to compute thermal stability and mean windspeed profiles from surface layer theory (eg., Businger et al, 1971). The stability is defined by the Obukov length,

$$L = -u^{*3} T / kg\overline{wT},$$

and the windspeed is related to L and u* by

$$U = (u^*/k)(\ln((z-d)/z0) + f(z/L)) \quad (1)$$

where k is the Von Karman constant, ≈ 0.35, z0 is the aerodynamic roughness length of the forest, approximately one tenth mean tree height and f is the stability function for windspeed as given in Businger et al, and others. The aerodynamic displacement length, d, of the trees is usually about 5/6 the mean tree height.

The turbulent velocity components, u and w, should be measured with a sonic anemometer, or at least with a fast response propellor bivane such as the MRI Vector vane (eg, see SethuRaman and Brown, 1976). The air temperature fluctuations should be measured with, for example, a microbead thermistor and correlated with the measured vertical velocity fluctuations to determine $\overline{wT}$ (Crabbe et al, 1985). The measurement height should be at least 5_{z0} above mean tree height, based on tower profile measurements in the New Brunswick forests reported in Crabbe et al (1984).

The average windspeed between forest and aircraft is often required for estimating drift, etc. This quantity can be derived by integrating equation (1) between height limits and dividing by the height difference. In neutral flow, where f=0, the equation for the average windspeed is

$$\langle U \rangle = \left(\frac{u^*}{k}\right)\left(\ln\left(\frac{HAC-d}{z0}\right) - \frac{h-d}{HAC-d}\left(\ln\left(\frac{h-d}{z0}\right) - 1\right) - 1\right) \quad (2)$$

where h is the lower limit of integration. Although equation (2) is only valid when the heights HAC and h are within the logarithmic profile region above the forest, little error is incurred by applying it in cases where h is below the logarithmic region, e.g., mean tree height.

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SUMMARY/SOMMAIRE

Some general remarks are presented on the design of a definitive field experiment on windborne droplet drift and deposition in aerial forestry spray applications. The role of the uncontrollable parameters, i.e. forest properties and, in particular, meteorology, is emphasized. Then, the variables in one aspect of the problem, the flightline offset distance, are discussed and an example of a suitable, i.e. economical but adequate, field experiment is described.

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